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TERRESTRIAL BRYOPHYTES AS INDICATORS OF AIR QUALITY IN SOUTHEASTERN OHIO AND ADJACENT WEST VIRGINIA[1]

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Abstract. Bryophyte community as well as individual moss species characteristics on soil were examined to determine relationships with proximity to three coal-fired power plants emitting SO_2 and a ferroalloy plant emitting chromium among their emission products. Woody vascular plant communities were relatively uniform, whereas bryophyte coverage was halved (from 3.36% to 1.47%) when comparing locations relatively distant from the plants with those closer. Other common community indices varied little with locality. Three moss species which showed the most consistent relationship to distance from the power plants, *Dicranum scoparium*, *Leucobryum albidum*, and *Polytrichum ohioense*, were mapped for presence or absence on 68 similar hillside habitats. *D. scoparium* and *L. albidum* consistently were absent in the area most influenced by the emission sources, while *P. ohioense* was less consistent in its absence. Presence or absence of indicator moss species proved more useful than community characteristics for indicating relative air quality.

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Bryophytes, as well as lichens, have been successfully used as indicators of air quality in a number of studies as reviewed by LeBlanc and Rao (1974). Some of these studies imply that increased SO_2 concentrations are the major cause of observed reductions in cover values and decreases in the number of species present, although other pollutants such as heavy metals, NO_x, HF, and O_3 are often present. Most studies examined epiphytic species; however, terricolous bryophytes were used as both indicators of SO_2 stress (Winner and Bewley 1978a, b) and airborne heavy metals (Ruhling and Tyler 1971).

Previous distributional studies in the area of lichen and bryophyte species on all substrates and habitats were inconclusive. Schutte (1976) reports an elevated Chromium content, 69.5 $\mu g\ g^{-1}$ dry wt., in the lichens *Parmelia caperata* and *P. rudecta* in woods southeast of the Sporn power plant in close proximity to a ferroalloy plant (fig. 1) compared to values of 1.8 at Salt Fork State Park and 12.8 at Hocking State Park, Ohio.

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Our study was initiated to determine if there were phytosociological and/or species differences among terricolous bryophyte communities of similar habitats at various distances from three coal-fired power plants and a ferralloy plant along the Ohio River. Measurements indicated that at times air in the power plant area is higher in SO_2 content than at some distance away (fig. 1). Terricolous bryophytes of this area were used as indicators of air quality as has been reported for other areas.

SAMPLING REGION

The region studied is underlain by sandstone and shale and consists of rolling topography with a mosaic of cultivated fields, pastures, woodlots, and small towns. Soil associations are Muskingham-Upshur and Muskingham-Latham, both characterized by shallow to moderately deep acid soils on strongly sloping to steep topography (Dotson 1962). Selection of areas for study was determined by the proximity to available mechanical air quality monitoring stations maintained by the power company (fig. 1).

During the first year of our study, quantitative community data on vascular and bryophyte vegetation was obtained from 5 sites sampled within 4-11 km of all 3 coal-burning power plants and the ferralloy plant where low level SO_2 pollution was measured, and 5 similar sites were sampled at least 24 km from any power plant where the yearly SO_2 concentrations were much lower (fig. 1). Only wooded southwest exposures (210°–245°) that had been previously identified on topographic maps were visited as possible sampling locations. Upon examination, the locations were judged suitable if they exhibited the following characteristics: 1) presence of most of the following vascular species *Quercus alba*, *Q. prinus*, *Q. velutina*, *Q. coccinea*, *Carya glabra*, *Cornus florida*, and *Sassafras albidum* in the canopy and shrub layers; 2) even distribution of age classes of woody species; 3) upper slope position on the hillside without major topographic irregularities such as dips, gullies, or stream beds; and 4) absence of obvious recent disturbances such as logging, grazing, fires, or windfalls. Because of the difficulty in locating sites which met these criteria, especially the latter, only 10 suitable locations were quantitatively sampled.

During the second year of our study, data on 3 selected moss species were obtained from sampling a 600 km² area encompassing the 3 power and ferroalloy plants. Five of the locations phytosocialogically sampled the previous year were included.

Sites were preselected on 6 Ohio and West Virginia topographic quadrangle maps. Most sites were relatively undisturbed woodlots occurring on southwest facing hillsides that met the same criteria used for the phytosociological part of the study, but several wooded church lawns and cemeteries were sampled because of their accessibility, and the high degree of disturbance in the area made it necessary to use them to increase the sample size.

PHYTOSOCIOLOGICAL MEASUREMENTS DURING FIRST YEAR

In 1975, phytosociological data were obtained from a 10×20 m quadrat at each of the 10 sites. In each quadrat, all trees identified were over 1.5 m high and their diameter at

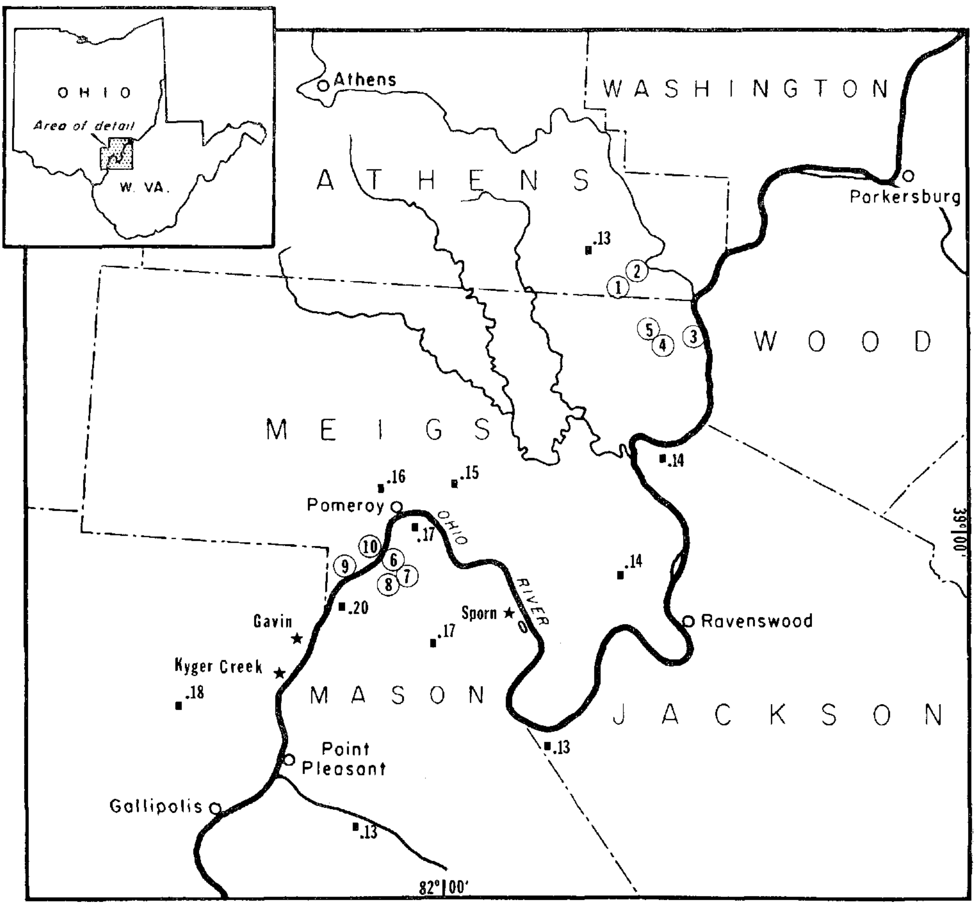

FIGURE 1. Map of study area. Circled numbers indicate the 10 locations sampled quantitatively the first year in relation to the power plants (★) and ferroalloy plant (○). SO_2 concentrations (in ppm SO_2) at mechanical monitoring stations (■) represent the mean of the maximum 3-hour ppm averages for each quarter from January, 1975 through December, 1976.

breast height (dbh) recorded if 5 cm or greater. Presence and Cover (Mueller-Dombois and Ellenberg 1974) were recorded for all vascular species below 1.5 m high using a Braun-Blanquet scale. The vascular plant comparisons were made to determine the similarity of sampling sites, and information about slope and aspect of each station were recorded.

Detailed bryophyte community data were determined at each site. Presence and cover of each species were measured in 40 one meter square quadrats placed in a predetermined pattern within each of the larger 10×20 m vascular plant sampling quadrats. Coverage was determined for each species using a modified Braun-Blanquet scale (r=presence less than 0.5%; +=greater than 0.5% but less than 1%; 1=greater than 1% but less than 5%; 2=greater than 5% but less than 10%; 3=greater than 10% but less than 25%; 4=greater than 25% but less than 50%; 5=greater than 50%). Percentage bare area (surface area not covered by recognizable plant material) was also recorded for each quadrat.

ANALYSIS OF DATA (FIRST YEAR)

Several phytosociological indices were analyzed for the bryophyte communities to determine which would be most useful as an indicator of air quality. Two indices of community similarity chosen to compare each air of sampling locations were 1) Sorenson's index of similarity based on presence of species only:

$$IS_s = 2c/(A+B) \times 100$$

where c=number of spp. common to both locations A and B, A=total number of ssp. in location B, and 2) a quantitative modification of Sorenson's index introduced by Bray and Curtis (1957) based on relative values of all species per stand: $IS_{BC} = Mw \times 100$ (where Mw=smaller quantitative value of a species common to both locations A and B). This value was determined by using the Braun-Blanquet scale number, 1 to 5, recorded for each species in each of the 40 quadrats of a location. Each scale number was first converted into the median value of the percentage range it represented. Then the mean was calculated from the forty values and used as the percentage cover of each species. These community similarity indices were calculated also for vascular plant species greater than 5 cm dbh. The sum of relative density, relative frequency, and relative dominance was used as the quantitative value.

An index of atmospheric purity (LeBlanc and DeSloover 1970) was calculated for each station except for the modification of using the mean percentages for f in the formula as calculated for the Bray-Curtis formula above:

$$IAP = \Sigma \frac{1}{n} (Q \times f)/10$$

(where n=number of spp. at any location, and Q=an ecolocial index determined from the mean number of species concurrent with any given species). The diversity indices were calculated with the Shannon-Wiener formula: $H = \Sigma_i^s = 1$ pi og_e pi; and Simpson's index:

$$D = \frac{N(N-1)}{\Sigma n(n-1)}$$

1

Values for species richness: $D = S-1/\log_e N$ (Margalef 1958) and evenness: $e = H/\log_e S$ (Pielou 1966) were calculated as well using the quantitative cover mean values, as above, instead of the number of individual moss plants.

SPECIES DISTRIBUTION DURING SECOND YEAR

In the second year (1976), the presence or absence of three mosses, *Dicranum scoparium* Hedw., *Leucobryum albidum* (Hedw.) Schimp., and *Polytrichum ohioense* Ren. Card. was recorded on 68 preselected southwest facing hillsides. Each location was examined by observation until either the 3 mosses were located or until their absence was determined. In assuring the latter, entire hillsides were often scanned.

Soils were sampled in 11 of the wooded localities. Three were selected because all 3 mosses were present, and 3 because all 3 mosses were absent. The sample for each locality was a composite of 7 to 10 subsamples taken at random on the hillside. Each subsample consisted of the top 2 cm of soil starting with the A_1 horizon in a 11.5 cm diameter circular core. Soils were analyzed for moisture content (fresh weight—oven dry weight = M.C.), organic matter (loss of weight on ignition), pH, and texture (hydrometer method of Bouyoucos 1951).

FIRST YEAR PHYTOSOCIOLOGICAL STUDY

The site similarity of the 10 locations samples in the first year of this study was confirmed by the analysis of vascular plant communities. No significant differences occurred using a t-test of significance between the 5 locations in the near-power-plant area compared with the 5 in that farther removed by any of the following parameters: 1) mean tree density and dominance for all individuals >5 cm. dbh; 2) density of selected tree class sizes; 3) mean shrub density; 4) percentage coverage by ground layer vascular vegetation; and 5) percent bare area. Bryophyte coverage, however, was different in the two areas. In the near-power-plant vicinity, mean cover for all quadrats was 1.47%, while it was 3.36% for all quadrats in the remote area. Using a t-test, the difference was significant at the 0.01 level when values were computed from the cover values of each of the 400 quadrats ($n=400$), but not significantly different for the 10 locations when compared ($n=10$).

No significant difference in bryophyte diversity was measured between the two areas. The total diversity in the near-power-plant area was 14 species, whereas 18 were present in the remote locations. The mean number of species per station was 7 for the near and 11 for the remote locations.

Using the indices previously described, similarity coefficients were calculated for both bryophyte and vascular plant communities (table 1). Results using Sorenson's index (IS_s) based on presence of species only indicated that sampled vascular plant communities in the near area had less in common with each other on the average (40%) than with communities in the remote area (47%). Community pairings within the remote area were relatively higher (50%), indicating their strong similarity in composition. Bryophyte community results, however, expressed a relatively high degree of similarity in composition within each respective area (75% in the remote area and 69% in the near) but a significantly less degree of similarity between pairings of bryophyte communities from the two areas (58%). Results using the quantitative index of Bray and Curtis (IS_{BC}) express a similar pattern (table 1).

TABLE 1

Mean Bryophyte and Tree Community Similarity Coefficients (%) for 3 Groups of Sampling Location Pairings.

Station Pairings*	Tree		Bryophyte	
	IS_s**	IS_{BC}***	IS_s	IS_{BC}
Remote Remote	50	43	73	53
Remote Near	47	33	58	30
Near Near	40	29	69	34

*Remote site with each remote site = 10 pairings, each remote site with each near site = 25 pairings, and each near site with each near site = 10 pairings.

**Qualitative index using presence absence data.

***Quantitative index based on importance values for tree communities and cover values for bryophyte communities.

Several diversity and phytosociological indices were examined for potential use in delineating areas affected by low level air pollution (table 2). No patterns were discernable in species evenness, Simpson's index, or the Shannon-Wiener index. For bryophyte communities, species number and species richness values were consistently lower at the near locations except for location 6, even though values for the woody vegetation did not exhibit this pattern. IAP values for bryophyte communities were also generally lower in the near locations but were too variable to successfully delineate zones of poor air quality.

Several common moss species showed significant differences in cover and frequency in the remote area when compared with the near-power-plant area (table 3). *Dicranum scoparium* was found in 31 of 200 quadrats with a mean percent cover of 0.3 in the remote area, but was absent from the 200 quadrats in the near area. *Polytrichum ohioense* had the greatest mean percent cover in the remote area at 1.6 whereas its mean was 0.3 for the near area. *Leucobryum albidum* appeared in 52 quadrats in the remote area with a mean percent cover of 0.4, but was present in only 7 quadrats in the near area having a mean cover value of 0.02. In terms of the mean percent cover for the

TABLE 2

Diversity Indexes for Bryophyte and Woody Vegetation Above 1.5 m; Index of Atmospheric Purity (IAP) and Community-Similarity Coefficients for Bryophytes in Sampling Stations.

Index	Remote Stations					Near Stations				
	1	2	3	4	5	6	7	8	9	10
Number of species										
Bryophytes	10	13	14	11	7	12	6	7	6	6
Woody vegetation	11	12	9	10	13	8	9	12	10	13
Species richness, D										
Bryophytes	.93	1.25	1.30	1.14	.68	1.19	.71	.83	.59	.53
Woody vegetation	2.91	3.07	2.17	2.18	3.04	2.08	2.37	3.02	2.35	3.23
Species evenness, e										
Bryophytes	.66	.84	.83	.89	.27	.94	1.04	1.22	.51	.56
Woody vegetation	1.33	1.26	1.18	1.26	1.24	1.42	1.09	1.03	1.36	1.32
Simpson's Index										
Bryophytes	1.98	2.55	3.76	2.91	1.15	3.08	2.81	5.87	1.47	1.61
Woody vegetation	10.49	9.63	4.64	6.83	8.85	7.00	3.53	3.71	8.28	9.82
Shannon-Wiener, H'										
Bryophytes	1.52	2.17	2.18	2.13	.52	2.32	1.86	2.37	.92	1.00
Woody vegetation	3.18	3.14	2.60	2.91	3.18	2.94	2.40	2.56	3.12	3.38
IAP-bryophytes	39	33	52	15	15	23	2	2	10	24
Index of Similarity*	67	81	100	72	67	77	60	48	60	60

*Stations were compared to the station with the greatest species number using Sorenson's Index, IS_s.

TABLE 3

Mean Percent Cover Values and Raw Frequency Values for Bryophyte Species in Sampling Stations Near to and Remote from 3 Coal-Burning Power Plants.

Index*	Remote Stations					Near Stations				
	1	2	3	4	5	6	7	8	9	10
*Amblystegium serpens***	—	—	.01(1)	—	—	.01(1)	—	—	—	—
Atrichum angustatum	.01(1)	.03(4)	.06(9)	.08(2)	.03(2)	.23(11)	.01(2)	.09(2)	.02(3)	2.23(11)
Bryoandersonia illecebra	—	—	.05(4)	—	—	—	—	—	—	—
Bryum lisae var. *cuspidatum*	—	—	—	—	—	.01(1)	—	—	—	—
Calypogeia trichomanis	—	.02(3)	.01(1)	—	—	—	—	—	—	—
Campylium hispidulum	.01(1)	—	—	—	—	—	—	.01(1)	—	—
Cephaloziella sp.	.01(1)	.04(6)	.02(3)	.01(2)	—	—	—	—	—	—
Dicranella heteromalla	.49(13)	2.17(17)	1.14(18)	.24(5)	.04(3)	.30(20)	.14(12)	.04(5)	.96(32)	.61(16)
Dicranum scoparium	.33(6)	.31(5)	.63(17)	.01(1)	.03(2)	—	—	—	—	—
Diphyscium foliosum	.01(1)	.31(12)	—	—	—	.09(2)	—	—	—	—
Fissidens bushii	—	—	—	—	—	—	—	.08(1)	—	—
Haplocladium microphyllum	—	.01(1)	.03(2)	—	—	0.4(4)	—	—	—	—
Hypnum imponens	—	.01(1)	—	.01(1)	—	—	—	—	—	—
Isoptygyrium elegans	—	—	.03(2)	.02(1)	—	.03(3)	—	.01(1)	.18(6)	.03(2)
Leucobryum albidum	.38(12)	.04(7)	1.52(25)	.21(7)	.01(1)	.11(6)	.01(1)	—	—	—
Lophocolea heterophylla	.03(4)	.09(12)	.01(2)	—	.01(1)	.01(2)	—	—	—	.01(1)
Plagiothecium denticulatum	—	—	—	.01(1)	—	—	—	—	—	—
Platygyrium repens	.04(4)	.04(4)	.02(3)	.06(8)	.01(1)	.11(7)	.02(3)	.02(3)	.02(3)	.05(8)
Polytrichum ohioense	2.86(18)	.59(8)	2.09(22)	.90(9)	1.50(7)	1.38(19)	.02(3)	—	—	—
Rhynchostegium serrulatum	—	.03(3)	.02(1)	.11(6)	—	.25(5)	.08(2)	.09(2)	.01(1)	.02(1)

*New frequency values in parenthesis, max. value=40. Absence of a number indicates absence of a species.

**Nomenclature: Crum, Howard 1973 Mosses of the Great Lakes Forest. Contributions from the University of Michigan Herbarium Vol. 10, pp. 1–404. University Herbarium, Univ. of Mich., Ann Arbor, MI.

40 quadrats at each station, only these three mosses appeared to show meaningful differences between the two areas. The other mosses were either inconsistent, less distinct, or too rare to be important as air quality indicators. *Atrichum angustatum* increased in cover in the near area, but it was not suitable for presence-absence mapping because of its ubiquitous presence. Total frequency of the liverworts as a group was noticeably lower in the near locations, having only 3 occurrences as compared to 35 in the remote locations.

PRESENCE-ABSENCE DATA OF SECOND YEAR

When the 3 moss species, *D. scoparium*, *L. albidum*, and *P. ohioense*, were individually recorded for presence or absence at 68 sites (figs. 2, 3, and 4), significant and consistent absence was found in an area in close proximity to the power plants for *D. scoparium* and *L. albidum*, but less distinctly for *P. Ohioense*.

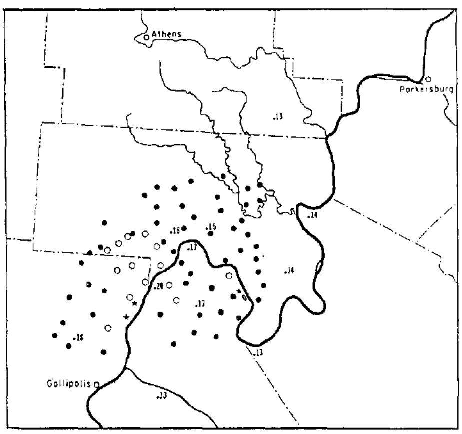

FIGURE 2. Distribution of *Dicranum scoparium*. Solid circles indicate presence at that site, open circles indicate absence at that site, SO_2 concentrations at sampling stations as in figure 1.

Soil moisture data were inconclusive. Generally, soil moisture values were higher at sampling sites in the area immediately encompassing the power plants and feroalloy plant, but the higher values did not correlate with the selected moss species presence or absence. Soil moisture data were difficult to interpret for so few samples over such a large area

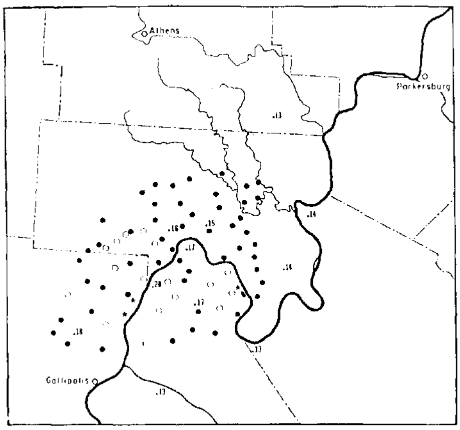

FIGURE 3. Distribution of *Leucobryum albidum*. Solid circles indicate presence at that site, open circles indicate absence at that site, SO_2 concentrations at sampling stations as in figure 1.

when the pattern of previous rainfall was unknown. Soil pH, organic matter content, and soil texture did not exhibit any relationship with moss distribution patterns for these species.

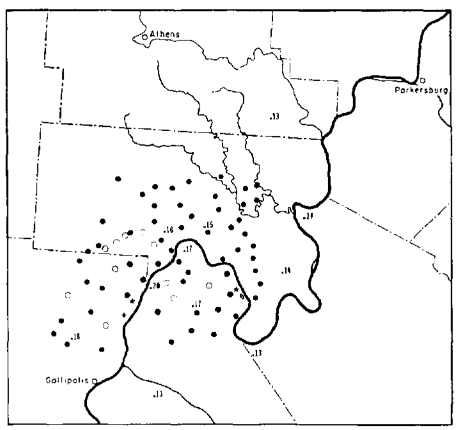

FIGURE 4. Distribution of *Polytrichum ohioense*. Solid circles indicate presence at that site, open circles indicate absence at that site, SO_2 concentrations at sampling stations as in figure 1.

DISCUSSION

Habitat differences are extremely important in the distribution of bryophytes or lichens in polluted zones. Gilbert (1970) found that the ability of a particular bryophyte species to exist in a polluted zone depended upon the substrate on which it grew and upon the amount of shelter it received. Our study attempted to diminish the effects of substrate and shelter by sampling only ground inhabiting bryophyte species on wooded hillsides subjectively determined to be similar. The similarity of these wooded hillside habitats is supported by the data recorded for the structure and composition of woody vegetation (table 2). Special attention was paid to slope aspect, tree density, and tree basal area, as these parameters were found to have significant positive correlations with percentage bryophyte cover in a study by Stringer and LaRoi (1970). The community similarity coefficients also indicate the relative similarity in the vascular vegetation of the habitats selected for sampling.

The sampling locations appeared to provide similar opportunity for bryophyte colonization and growth based on slope aspect and woody vegetation data; however, ground-inhabiting bryophyte cover and diversity were less and the species composition of the communities was different in the area in close proximity to the power plants. These results are similar to those reported for some polluted areas by LeBlanc and Rao (1974) and Winner and Bewley (1978a, b).

Studies on various organisms have attempted to use special indices of species diversity as a means of indicating perturbations in the environment (Adams and Barrett 1976; Bulan and Barrett 1971; Karr 1968; and Wilham and Dorris 1968). In our study, the diversity indices examined were of no greater value in differentiating between sampling location in the two areas than a simple determination of the number of species present in a given area (table 2).

The usefulness of the index of atmospheric purity (IAP) of LeBlanc and DeSloover (1970) was also examined. This index has been used in several air pollution studies (LeBlanc and DeSloover 1970; LeBlanc *et al* 1972; LeBlanc *et al* 1974; Stringer and Stringer 1974) and takes advantage of both the simplification of cryptogamic communities near sources of air pollution and the relative change in species composition in these communities. The IAP values calculated in our study (table 2), although often higher for locations in the control area, were not found to be consistent for delineating effected areas.

Indices of community similarity can be potentially used in the delineation of pollution zones. For example, Newberry (1974) examined corticolous lichen communities on four host tree species and correlated their distribution patterns with atmospheric SO_2 concentrations in proximity of a sulfate process paper mill. Using a qualitative index of similarity, he compared lichen communities growing near the paper mill and found that the index of similarity increased with distance from the paper mill. This approach was examined in our study using the qualitative community similarity index, but as with our IAP values, it proved to be inconsistent.

Mapping the presence or absence of a particular lichen or bryophyte species as a means of indicating the effect and degree of air pollution has been demonstrated in numerous studies (Gilbert 1970; LeBlanc and DeSloover 1970; Newberry 1974; Showman 1975; and Stringer and Stringer 1974). The complete absence of *Dicranum scoparium* and the dramatic reduction in cover of *Polytrichum ohioense* and *Leucobryum albidum* in the near-power-plant area suggested their potential as indicator species. Void areas existed in the distribution patterns of *Dicranum scoparium* and *Leucobryum albidum* (figs. 2 and 3) and *D. scoparium* was absent from sites downwind, of the Gavin and Kyger Creek Plants, but was present in most sites located near the Sporn Plant (which burns coal of lower sulfur content and has relatively high stacks). Similar to *D. scoparium*, the distribution pattern of *L. albidum* also showed a void area in the vicinity of the Gavin and Kyger Creek plants, although this was not as well defined. Unlike *D. scoparium*, *L. albidum* was noticeably absent in an area around the Sporn Plant. This small void area may or may not be due to activities of the power plant, as the presence of a ferroalloy plant in the immediate vicinity must also be considered a potential pollution source. No distinct void area appeared near the power plants in the distribution of *Polytrichum ohioense*.

Nash and Nash (1974) report a reduction of chlorophyll in mature gametophytes of *Leucobryum glaucum* at experimental SO_2 concentrations of 1.0 ppm after 12 hours. *Dicranum scoparium* sufferred a significant reduction at concentrations between 2.0 and 4.0 ppm. In their experiments, *Polytrichum ohioense* was found to be even more resistent. All of these SO_2 concentrations were greater than the average SO_2 concentrations recorded by mechanical monitoring stations within study area. Nash and Nash (1974), however, fumigated different stages of the life cycle of the resistant moss *P. ohioense* and found that the protonema were killed at concentrations as low as 0.2 ppm SO_2. They concluded that *P. ohioense* was sufficiently sensitive to SO_2 so that the presence of moderate levels of SO_2 in an area may exclude that species.

In a section of southeastern Ohio and adjacent West Virginia, terricolous bryophyte communities on southwest facing hillsides showed reduction of mean cover from 3.36% in a control area to 1.47% near coal-burning power plants. Vascular plant community data, including low vegetation cover and canopy species importance values, did not exhibit any significant differences. Although it would be possible to use reduction of mean cover of bryophytes as an indicator of relative air quality, it is a time consuming measurement and other indices of bryophyte community structure were found to be inconsistent. The presence or absence of particular common indicator moss species, in this case *Dicranum scoparium*, *Leucobryum albidum* and *Polytrichum Ohioense*, was found to be an easily measured indicator of relative air quality.

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